INTERNATIONAL RESEARCH JOURNAL OF ENGINEERING & APPLIED SCIENCES
ISSN: 2322-0821(O) ISSN: 2394-9910(P)
VOLUME 10 ISSUE 3 Jul 2022 - Sep 2022
www.irjeas.org

Original Article

Implementation of Fuzzy Logic Controller Based DSTATCOM for Power Quality Enhancement in Distribution Systems

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https://doi.org/10.55083/irjeas.2022.v10i03001

Received: 25 April 2022; Received in revised form: 12 July 2022; Accepted: 07 July 2022

Abstract: This research work, presents Fuzzy Logic Controller (FLC) based D-STATCOM for power quality (PQ) enhancement in power distribution network. In the power distribution system, PQ is the major issue that is occurring due to non-linearity and dynamic changes in the connected loads. The proposed work utilizes FLC for generating switching Pulses for IGBT switches in the D-STATCOM to enhance quality of power in distribution systems. This research work also shows superior performance over conventional PI controllers in mitigation of harmonics by using proposed FLC topology. The proposed system is simulated with Matlab/Simulink software to ensure effective realization.

Keywords: D-STATCOM, Fuzzy Logic Controller, PI controller, Power Quality, Voltage Source Inverter.

1. INTRODUCTION

In these days, the primary source for power generation is considered from the non-renewable energy resources, but the over usage of non-renewable energy resources will leads to the extinction of the fossil fuels and cause environmental threats. This may also leads to the quality of power related issues in the distribution systems. So, to overcome this, power to the distribution systems is considered from the renewable energy resources [1]. As mentioned in [2]-[3], some of the applications of FACTS devices like stabilization of voltage, utilization of energy, mitigation of harmonic contents, compensation of PQ related issues are employed. There are other applications which are known as compensation of reactive power, regulation of voltage, reduction of power loss is depicted in [4]-[5]. In the meanwhile, for providing the protection of grid, specific role of the PE (power electronic) converters has gained more popularity along with RES [6].In the 1980's, FACTS devices were introduced. FACTS are meant to enhance the efficiency of the resources related to power systems [7]. This will deploys the factors that influence the harmonics which are

emitting by the power converters. It should be emphasized, however, that the system operator can specify different, more stringent restrictions. Passive filters are often employed to minimize the emission of harmonics [8]. The creation of harmonics can also be influenced by using converter control and modulation. The use of a selective harmonics compensation algorithm is one technique to accomplish this. These strategies are attracting attention when using a weak grid converter because the voltage is more prone to harmonics and other types of disturbances [9]. Controlling reactive power flow in the network is crucial for the power system to operate at its best. Some of the facts based components like D-STATCOM (distribution static var compensator), SVC (Static VAR Compensator) and UPQC (Unified Power Quality Conditioner) will compensate the flow of reactive power. This devices can also able to control the voltage, line impedance and angle between the phases attaining from sending end side to receiving end side [10]. The combination of facts devices with power electronic converters are gaining a major importance in employing and controlling the power system analysis. As proposed in [11], the planning, operation and calculation will leads to finding a solution for power flow in the power network. However, D-STATCOM modeling's effects on PQ problems have previously drawn a lot of attention [12].This will leads to mitigation of voltage fluctuations, control of voltage at distribution side and reduction of load related problems. As mentioned in [13], the DSTATCOM can also be defined as a coupling transformer, DC-AC converter and the ESS (Energy Storage devices) that are implemented in the distribution systems. In contrast to a D-STATCOM, which is utilized for dynamic compensation at the distribution level or at the load end, STATCOM at the transmission level only manages fundamental reactive power and provides voltage support. To correct imbalances or distortions in the source current or supply voltage, a flexible device known as D-STATCOM can also be used [14, 15].It was suggested that repetitive controllers (RC) be used to lower voltage and current harmonics [16].This controller used a conventional PI controller topology to address voltage and current problems. Regardless of whether it is used in a single structure or a hybrid structure, this controller improves system performance. It is possible to use this topology and PR controller in this [17]. This paper proposes an implementation of Fuzzy Logic controller based D-STATCOM for enhancing PQ in the power distributions systems. In this section depicts about the introduction and literature review of the existing methods, section-II explains about the system description and section-III explains about the performance of proposed controller, section-IV describes about the obtained simulation results and section-V depicts about the conclusion of the system.

2. SYSTEM DESCRIPTION

Figure-1 depicts about the schematic representation of D-STATCOM which is in shunt connection to the grid. The primary source to non-linear loads/unbalanced loads is considered from A 3-Phase AC grid. Due to non-linearity in the loads the grid will get effected by the power quality related issues. Some facts devices are used to compensate the quality of power problems like harmonics. In this work D-STATCOM is implemented. It is in shunt (parallel) to the grid. In D-STATCOM, the power supply is derived from a DC source and then passed through an inverter circuit to produce AC power. Using the new controlling topology known as FLC, the pulses are delivered to the inverter. The voltage at DC link will be regulated by this FLC. To reduce the harmonics in the system, the FLC based D-STATCOM will inject the necessary compensating current into the three-phase grid.

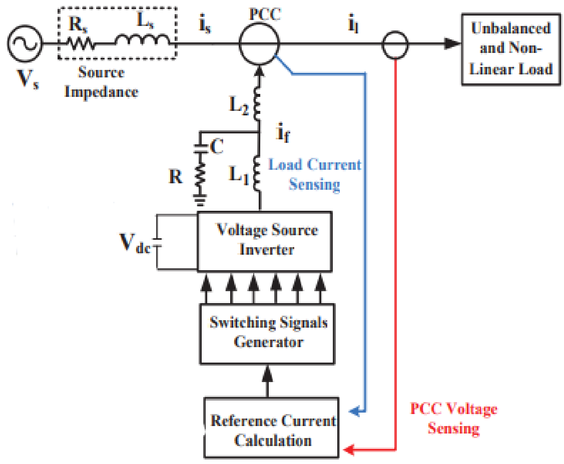

Figure 1 - D-STATCOM Structure

The selection of power factor angle by using theory of instantaneous symmetrical components can be expressed as below:

$$\angle\{a v_{sb} + v_{sa} + a^2 v_{sc}\} = \angle\{a i_{sb} + i_{sa} a^2 i_{sc}\} + \varphi^+ \ (1)$$

By rewriting the above equation can be obtained as follows:

$$i_{sa}(v_{sb} - v_{sc} - 3\gamma(v_{sa} - v_0)) +$$
$$i_{sb}(v_{sc} - v_{sa} - 3\gamma(v_{sb} - v_0)) +$$
$$i_{sc}(v_{sa} - v_{sb} - 3\gamma(v_{sb} - v_o)) = 0 (2)$$

Where, $\gamma = tan\, \varphi +$,angle$\varphi + = 0$, hence$\gamma = 0$, is used for UPF operation.

P_{lavg}, the load's average active power, is supplied by the source, and the load's oscillating component is supplied by the compensator. Hence,

$$i_{sa} v_{sa} + i_{sb} v_{sb} + i_{sc} v_{sc} = p_{lavg} \ (3)$$

When the inverter is working perfectly, the source only supplies the load's average power. The source must compensate for the losses (Ploss) in the VSI because the switches are not ideal.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = M^{-1} \begin{bmatrix} 0 \\ 0 \\ P_{lavg} + P_{loss} \end{bmatrix} (4)$$

Where,

$$= \begin{vmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ v_{sa} & v_{sb} & v_{sc} \end{vmatrix} (5)$$

Where, x_1, x_2 and x_3 are stated as

$$x_1 = -v_{sc} - 3\gamma(v_{sa} - v_o) + v_{sb}$$

$$x_2 = -v_{sa} - 3\gamma(v_{sb} - v_o) + v_{sc}$$

$$x_3 = -v_{sb} - 3\gamma(v_{sc} - v_o) + v_{sa}$$

Hence, the reference currents can be given as

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \begin{bmatrix} i_{la} - i_{sa}^* \\ i_{lb} - i_{sb}^* \\ i_{lc} - i_{sc}^* \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = M^{-1} \begin{bmatrix} 0 \\ 0 \\ P_{lavg} + P_{loss} \end{bmatrix} \quad (7)$$

The generation of pulses to the D-STATCOM is depicted in figure 2(a) for single phase. The three phases underwent the same analysis.

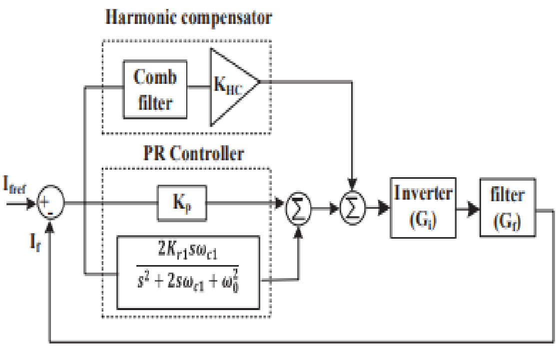

Figure 2(b) - Schematic representation for comb filter along with PR-controller

2.1. PR controller:

PR controller is a combination of proportional term and a resonant term with a high gain which is similar to the frequency. The following frequency response is supplied by the controller PR:

$$G_{pr}(s) = k_p + k_r \frac{s}{s^2+\omega_0^2} (8)$$

$$G_{pr}(s) = k_p + k_r \frac{2\omega_c s}{s^2+2\omega_c s+\omega_0^2} (9)$$

Where ω_c denotes the cutoff frequency, gain constants are denoted by K_r and K_p. Resonant frequency is denoted by ω_0.

2.2. COMB Filter:

The implementation of comb filter will add signal to the delayed version of the signal to obtain the required outputs. Feedback form and feed-forward form are the two types of COMB filters in which the input signal consists of the addition of delayed signal. These two types are expressed in the equations below.

$$H(\omega) = (1 + \alpha e^{-ST}) (10)$$

$$H(\omega) = \frac{1}{(1-\alpha e^{-ST})} (11)$$

Likewise, Fig. 2(b) shows that the suggested controller consists of a proportional resonant controller and a harmonic compensator (HC) based on a comb filter with a gain KHC. The reference currents are produced using the stationary reference (abc) frame of the instantaneous symmetrical component theory. The odd order no. of harmonics of current being are formulated after comparing the actual currents by the reference currents. The error for fundamental harmonic components will be processed by the PR controller for comb filter. Comb filter is tuned to produce the resonant peak at a frequency that is (2n+1) times the fundamental frequency. As a result, the comb filter can compensate for all dominant harmonics. The output of the comb filter can be tuned for enhancing the more compensation of harmonics and maintaining system stability. The range of tuning should be in the limits of 10 dB and 30^0. The below eq.12 depicts the resonant component for each individual harmonic which is described by implementing PR-controller with its transfer function.

$$G_{pr}(s) = K_p + \frac{2K_r s\omega_c}{s^2+2\omega_c s+\omega_0^2} + \sum_{i=5,7,11,13} \frac{2K_{ri} s\omega_{ci}}{s^2+2\omega_{ci}+\omega_0^2} (12)$$

Eq.13 and eq.14 depicts the transfer function of the PR+FF (Gpr1) and PR+FB (Gpr2) controllers. Along with the basic PR controller, it also includes a harmonics compensator for the 5th, 7th, 11th, and 13th harmonics components. Length of the delay is denoted byτ, the scaling factor is depicted by ω which is applied to the delayed signal. For each dominant harmonics, the comb filter was behaving as a resonant filter. The transfer function of LCL filter and inverter is depicted in Equations 15 and 16.

$$G_{pr1}(s) = K_{p1} + \frac{2K_{r1} s\omega_{c1}}{s^2+2\omega_{c1}s+\omega_0^2} + (1 + \alpha e^{-ST}) (13)$$

$$G_{pr2}(s) = K_{p1} + \frac{2K_{r1} s\omega_{c1}}{s^2+2\omega_{c1}s+\omega_0^2} + \frac{1}{(1-\alpha e^{-ST})} \quad (14)$$

$$G_f = \frac{I_i(s)}{V_i(s)} = \frac{1+sCR+s^2L_gC}{L_s(s^3L_pC+S^2CR+s)} (15)$$

$$G_i = e^{-sT_d} = \frac{1}{1+sT_d} (16)$$

It is possible to compute the transfer function from the overall system.

3. PROPOSED CONTROLLER (FLC)

In this research work, proposed FLC controller to control D-STATCOM operation. The FLC is a novel controller compared to conventional PI controllers. By using this controller the system response and stability improved. In this controller the structure is very simple and acts as a human-mind. Here used a set of logics to produce operation of FLC. There is no mathematical approach required. This controller is easy to construct as well as to implement. In this controller mainly three stages i.e., input stage (fuzzification), output stage (defuzzification) and inference stage (rule-based). The figure-3 shows the step by step process in FLC.

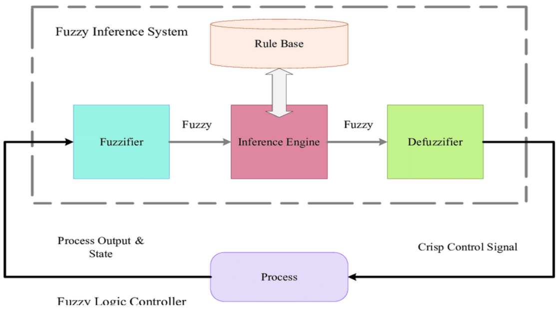

Figure 3 - Block Diagram of FLC

The figure below depicts the Fuzzy Logic Controller's membership functions. There are two inputs considered, voltage error in figure (4) and voltage change in error in figure (5), and the output i.e. power loss is displayed in figure (6).

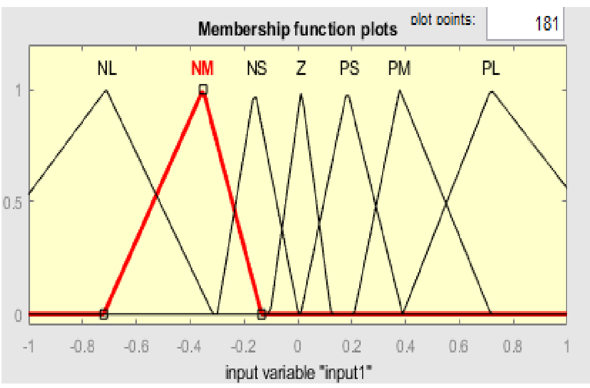

Figure 4 - Voltage error

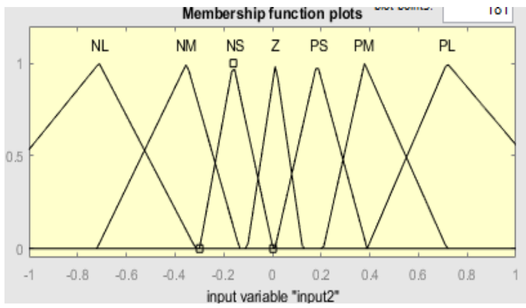

Figure 5 - Voltage change in error

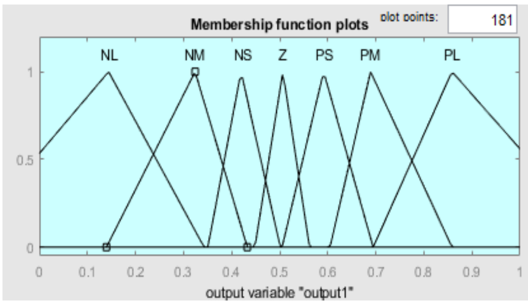

Figure 6 - Power loss error

In this proposed work, the dc link voltage control is more significant. By controlling DC link voltage, the D-STATCOM operation smoothly controlled. So, here with the help of FLC, the voltage at dc link is controlled. The below table shows the rules, which are implemented in proposed system.

Table 1 - Rules of FLC

E/CE	NB	NS	ZE	PS	PM
NB	NM	NS	NS	PS	PM
NS	NM	NS	ZE	PS	PM
ZE	NM	NS	ZE	PS	PM
PS	NM	NS	ZE	PS	PM
PB	NM	NS	PS	PS	PM

The above table depicts the rules of FLC. It consists of the 5x5=25 rules. In this negative big, negative medium and small is denoted with NB, NM and NS. Similarly, positive big, medium and small denotes PB, PM and PS. Whereas ZE depicts the zero error.

4. SIMULATION RESULTS

The proposed method can be evaluated by using Matlab/Simulink Software. A 3-phase grid system is considered with a rating of 75.35 kVA 3φ-load.Here mainly five cases are considered. For compensating the harmonics and provide reactive power to the load fuzzy logic controller based D-STATCOM is used. Table-2 describes about the parameters that are considered while implementing

ISSN(E) 2322-0821, ISSN(P) 2394-9910

the work. Whereas table-3 examines the controller parameters that are assumed while evaluating the results.

Case:-1 Without compensation

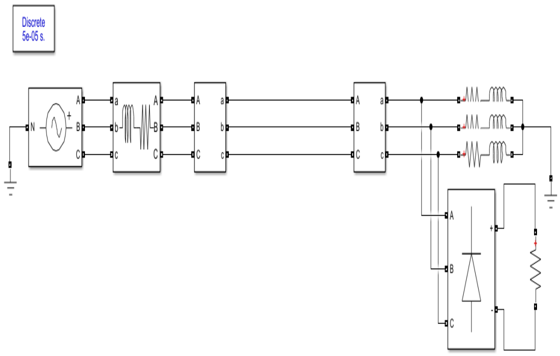

Figure 7- Simulink Diagram of distribution system without compensation

The implemented simulation diagram of distribution system without any compensation is shown in above figure-7. Here connected 3-phase distribution grid to unbalanced and non-linear load. Because of these loads, power quality issues are arised in distribution system and load. The obtained result is shown below.

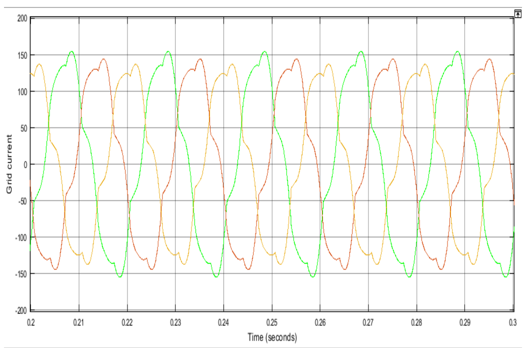

Figure 8- Grid current under without compensation

The above figure will depicts about the variations in the current waveform of the grid. It is having an amplitude of 150A but not in the sinusoidal form. That means it has the more harmonic content.

Case ii: with compensation

Figure 9 will explains about the simulation diagram of the proposed system after using the D-STATCOM. The power supply is considered from the grid to the loads.

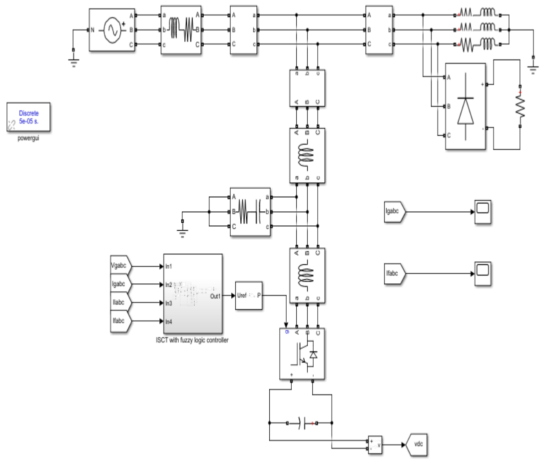

Fig 9- Simulation Diagram of distribution system with compensation

A D-STATCOM is in parallel to the grid which consists of the dc source, inverter and filter. The pulses give to the inverter is considered by using different controller. In this mainly 4 controllers are considered. They are PR controller, PR+FF controller, PR+FB controller and Fuzzy Logic controller. The obtained results by using all these controllers are depicted below.

4.1. Using PR Controller:

The supply from grid is given to the nonlinear loads and unbalanced loads. To overcome the PQ related problems in the distribution system occurred due to non-linear loads a D-STATCOM is in shunt to the grid. This D-STATCOM is controlled by a PR controller. The below figures shows the results obtained by using the PR controller. The performance results of grid current and filter current is shown below.

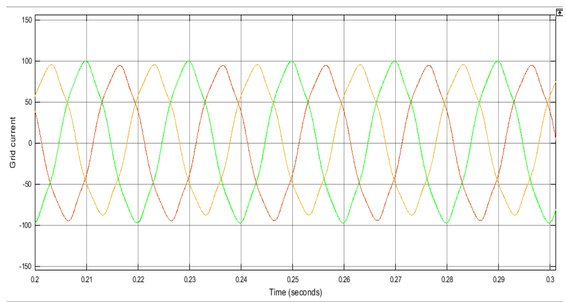

Figure 10- Grid current obtained after compensation by using PR Controller

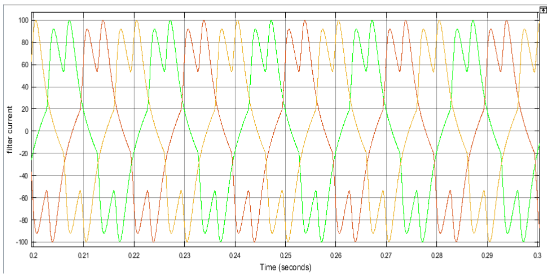

Figure 11- Filter current obtained after compensation by using PR controller

4.2. Using PR+FF Controller:

The supply from grid is given to the nonlinear loads and unbalanced loads. To overcome the PQ related problems in the distribution system occurred due to non-linear loads a D-STATCOM is in shuntto the grid. This D-STATCOM is controlled by a PR+FF controller. The below figures shows the results obtained by using the PR+FF controller. The performance results of grid current and filter current is shown below.

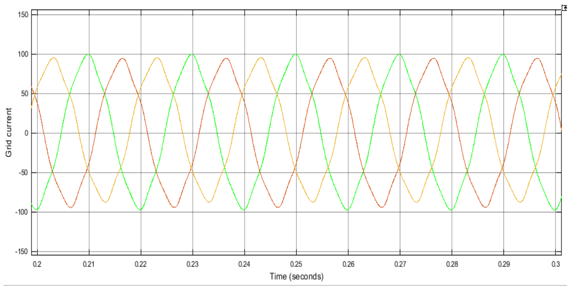

Figure 12- Grid current obtained after compensation by using PR+FF Controller

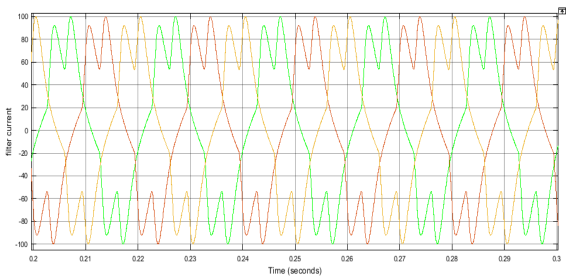

Figure 13- Filter current obtained after compensation by using PR+FF Controller

4.3. Using PR+FB Controller:

The supply from grid is given to the nonlinear loads and unbalanced loads. To overcome the PQ related problems in the distribution system occurred due to non-linear loads a D-STATCOM is in shunt connection to the grid. This D-STATCOM is controlled by a PR+FB controller. The below figures shows the results obtained by using the PR+ FB controller. The performance results of grid current and filter current is shown below.

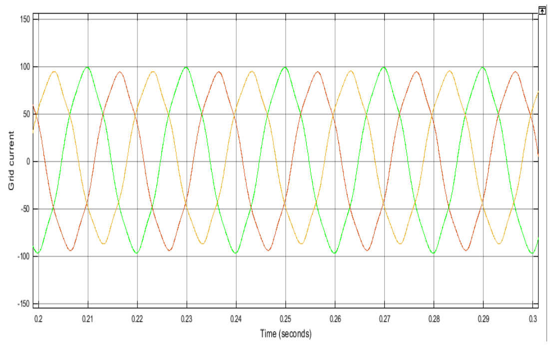

Figure 14- Grid current obtained after compensation by using PR+FB Controller

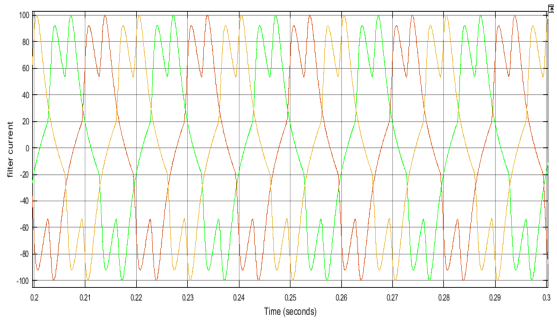

Figure 15- Filter current obtained after compensation by using PR+FB Controller

1) Sudden change of load.

In this case, tested the distribution system under sudden change of load because in any power system the load is not constant. It varies time to time. So, the proposed system must produce good performance under variable loads.so, here tested the proposed system with PR+FB controller topology for D-STATCOM under sudden change of load. The obtained results are shown below.

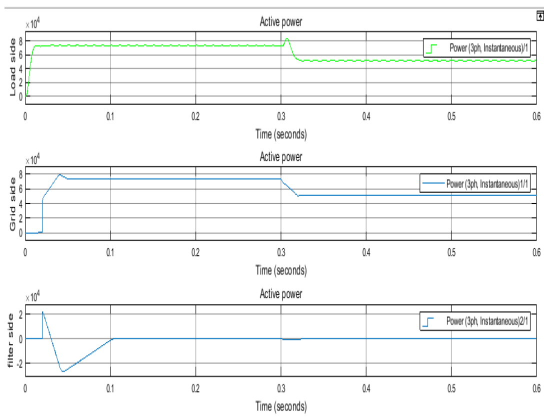

Figure 16- Active power attained under sudden change of load by using PR+FB Controller

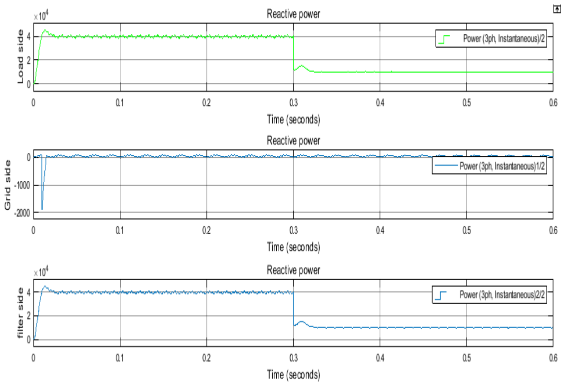

Figure 17- Reactive power attained under sudden change of load by using PR+FB Controller

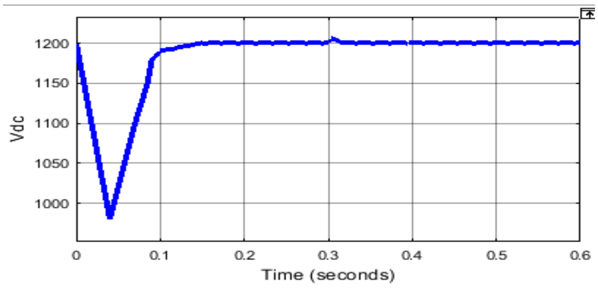

Figure 18- DC Link Voltage (Vdc) obtained under sudden change of load using PR+FB controller

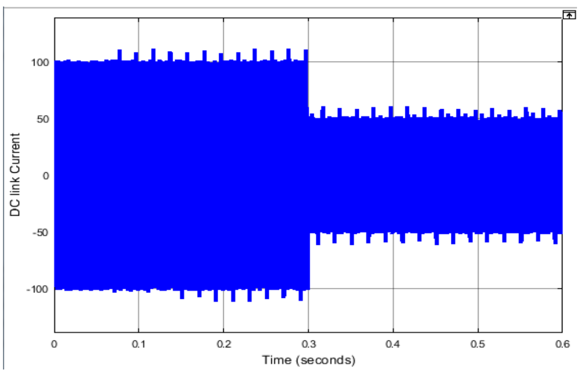

Figure 19- DC Link Current (Idc) obtained under sudden change of load using PR+FB controller

4.4. Using FLC: Here implemented FLC topology for shunt connected D-STATCOM to improve PQ issues in the proposed system. Because in distribution system major loads are non-linear and unbalanced loads produce power quality problems. In previous cases implemented different conventional controlled topologies for D-STATCOM to improve power quality. So, by using FLC D-STATCOM; it shows best performance compared to conventional controlling topologies.

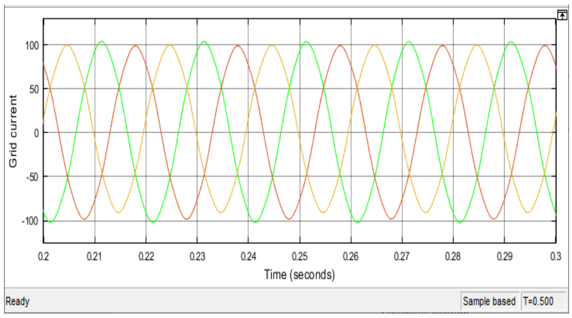

Figure 20- Grid current obtained with compensation using Fuzzy Logic Controller

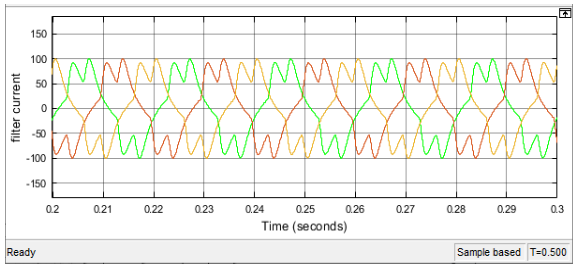

Figure 21- Filter current obtained with compensation using Fuzzy Logic Controller

1) Sudden changing of Load:

In this condition, dynamic change of load is occurred there would be some changes obtained in the distribution system at the time of implementing Fuzzy Logic Controller. The below figure will depicts about the simulation diagram consists of the sudden changes in the load.

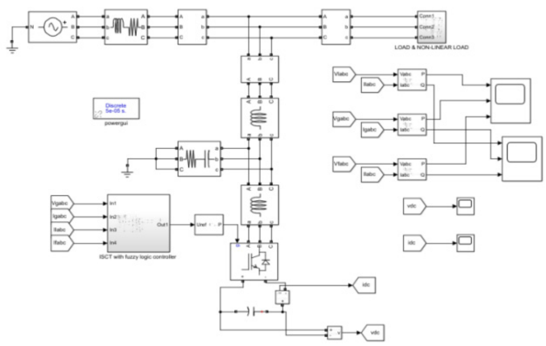

Figure 22- Simulation diagram of Fuzzy based D-STATCOM with varying load

The below figures depicts about the simulation results of active power, reactive power at grid side, load side and filter side. The DC link voltage and current at dc side by using Fuzzy logic controller is shown.

ISSN(E) 2322-0821, ISSN(P) 2394-9910

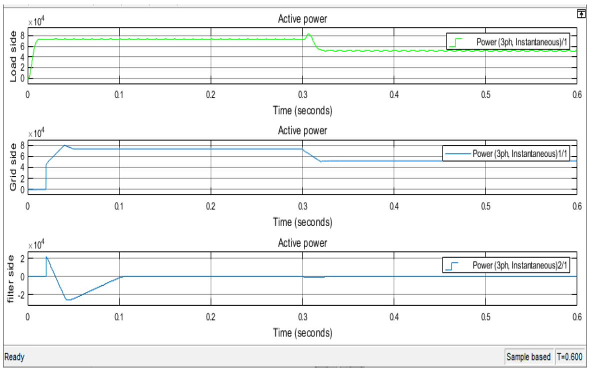

Figure 23- Active power obtained using FLC during a sudden change in load

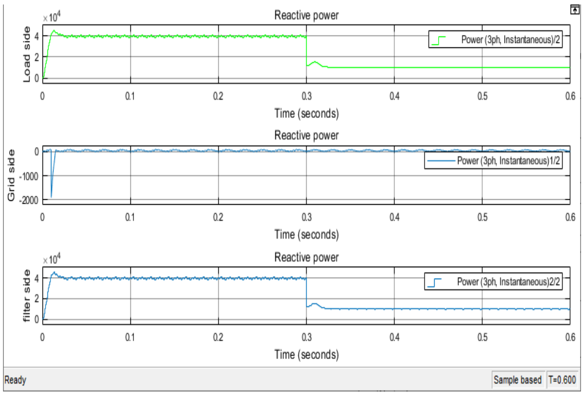

Figure 24- Reactive Power attained by FLC under a sudden change in load

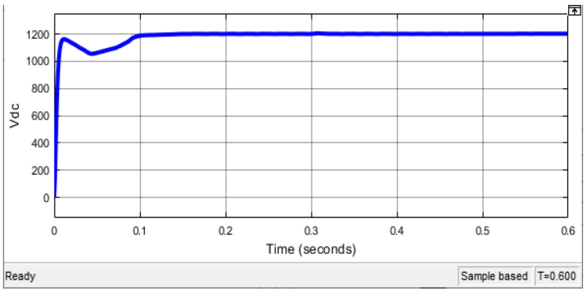

Figure 25- FLC is used to obtain DC Link Voltage under a sudden change in load.

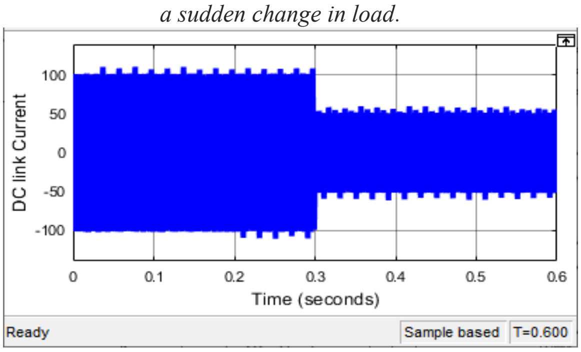

Figure 26- DC Link Current obtained using FLC under a sudden change in load

Table 2 – Parameter Comparison with and without compensation

Parameter	Without compens-ation	With Compensation			
		PR	PR+ FF	PR+FB	FLC
THD of Grid current at Phase-A(Ia)	11.49%	4.20%	4.22 %	4.04%	1.37 %
THD of Grid current at Phase-B(Ib)	12.19%	4.43%	4.44 %	4.26%	1.42 %
THD of Grid current at Phase-C(Ic)	12.83%	4.64%	4.65 %	4.45%	1.50 %

After implementing proposed fuzzy logic controller for D-STATCOM to improve power quality in Distribution systems gives more accurate result compared to without compensation and different conventional methods with compensation. As compared to conventional methods the fuzzy logic D-STATCOM produces less than 2% THD for 3-phase grid currents. The above table clearly shows the FLC D-STATOM more accurate compared to all conventional methods.

5. CONCLUSION

In this Research work Implemented, a FLC based D-STATCOM for enhancing PQ related problems in distribution system and tested the FLC-DSTATCOM operation under with compensation and without compensation. The operation and performance of FLC-DSTATCOM is compared with Conventional methods of PR, PR+FF and PR+FB controller. Compared to conventional methods, Proposed FLC-DSTATCOM provided good response along stability. The proposed controlling topology i.e.., FLC is used with the combination of PR-controller and Comb filter for compensating the multiple harmonics at constant frequency. It is implemented by using the rule based system. The DC link voltage in the system is regulated by this fuzzy logic controlling topology. So, that the good PQ is enhanced in the distribution system. The entire proposed FLC-DSTATCOM operation is implemented and tested in MATLAB/SIMULINK software.

ISSN(E) 2322-0821, ISSN(P) 2394-9910

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Conflict of Interest Statement: *The authors declare that there is no conflict of interest regarding the publication of this paper.*